

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re International Application of

Koji KIKUSHIMA

International Application No.: PCT/JP2004/012847

International filing date: September 3, 2004

For: OPTICAL SIGNAL RECEIVER, OPTICAL SIGNAL RECEIVING  
APPARATUS, AND OPTICAL SIGNAL TRANSMITTING SYSTEM

VERIFICATION OF TRANSLATION

Honorable Commissioner of Patent and Trademark  
Washington, D.C. 20231

Sir:

Kenichi KAKINUMA residing at c/o TANI & ABE, No. 6-20, Akasaka  
2-chome, Minato-ku, Tokyo 107-0052, Japan, declares:

(1) that he knows well both the Japanese and English  
languages;

(2) that he translated the claims of the  
above-identified International Application from Japanese to  
English;

(3) that the attached English translation is a true  
and correct translation of the claims, specification and  
drawings of the above-identified International Application  
to the best of his knowledge and belief; and

(4) that all statements made of his own knowledge  
are true and that all statements made on information and belief  
are believed to be true, and further that these statements  
are made with the knowledge that willful false statements and  
the like are punishable by fine or imprisonment, or both, under  
18 USC 1001, and that such false statements may jeopardize  
the validity of the application or any patent issuing thereon.

April 21, 2005

Date

*Kakinuma*

Kenichi KAKINUMA

10/532900

JC14 Rec'd PCT/PTO 27 APR 2005

22/pri

APPLICATION FOR UNITED STATES LETTERS PATENT

INVENTOR(S): Koji KIKUSHIMA

INVENTION: OPTICAL SIGNAL RECEIVER, OPTICAL  
SIGNAL RECEIVING APPARATUS, AND  
OPTICAL SIGNAL TRANSMITTING SYSTEM

S P E C I F I C A T I O N

## DESCRIPTION

OPTICAL SIGNAL RECEIVER, OPTICAL SIGNAL RECEIVING  
APPARATUS, AND OPTICAL SIGNAL TRANSMITTING SYSTEM

5

## TECHNICAL FIELD

[0001]

This invention relates to an optical signal receiver  
and optical receiving equipment that are used for  
10 transmission of an optical signal in which wide-band  
signals are frequency-modulated (FM: Frequency  
Modulation), and to an optical signal transmission system  
that uses the optical signal receiver or the optical signal  
receiving equipment. More specifically, this invention  
15 relates to an optical signal receiver and optical signal  
receiving equipment that are used for optical signal  
transmission of multichannel picture signals each of which  
is amplitude-modulated (AM: Amplitude Modulation) or  
quadrature-amplitude-modulated (QAM: Quadrature  
20 Amplitude Modulation) and that are  
frequency-division-multiplexed, and an optical signal  
transmission system that uses the optical signal receiver  
or the optical signal receiving equipment.

## 25 BACKGROUND ART

[0002]

Conventionally, as an optical signal receiver,

optical signal receiving equipment and an optical signal transmission system that transmit multichannel picture signals each of which was amplitude-modulated or quadrature-amplitude-modulated and that have been  
5 frequency-division-multiplexed, there are known an optical signal receiver, optical signal receiving equipment, and an optical signal transmission system each of which uses an FM batch conversion method of frequency-modulating collectively picture signals that  
10 have been frequency-division-multiplexed.

[0003]

The optical signal transmitter and the optical signal transmission system that use this FM batch conversion method has been adopted in International Standards ITU-T  
15 J. 185 "Transmission equipment for transferring multi-channel television signals over optical access networks by FM conversion" (see Non-patent document 1).

[0004]

--- --FIG. 1 shows the configuration of the optical signal  
20 receiver and the optical signal transmission system that use the conventional FM batch conversion method. FIG. 2A, FIG. 2B, and FIG. 2C show signal spectra in positions of A, B, and C in FIG. 1. The optical signal transmission system shown in FIG. 1 comprises: an optical signal  
25 transmitter 80 having an FM batch conversion circuit 81, a light source 82, and an optical amplifier circuit 83; an optical transmission path 85; an optical signal receiver

90 having a photoelectric conversion circuit 91 and an FM demodulator circuit 92; a set top box 93; and a television receiver 94. FIG. 2A, FIG. 2B, and FIG. 2C show spectra of A, B, C in FIG. 1, respectively. This correspondence  
5 is the same for spectra of A, B, and C in subsequent figures.

[0005]

In FIG. 1, in the optical signal transmitter 80, the picture signals that have been frequency-division-multiplexed as shown in FIG. 2A are  
10 converted to a single frequency-modulated signal that occupies a wide band, as shown in FIG. 2B, by the FM batch conversion circuit 81. The frequency-modulated signal is allowed to intensity-modulate the light source 82. Further, the optical signal is amplified by the optical  
15 amplifier circuit 83 and transmitted in the optical transmission path 85. In the optical signal receiver 90, the optical signal is returned to the electrical signal by photoelectric conversion in the photoelectric conversion circuit 91. This electrical signal is a  
20 wide-band frequency-modulated signal, which is frequency-demodulated by the FM demodulator circuit 92 to yield picture signals that have been frequency-division-multiplexed, as shown in FIG. 2C. The picture signals thus demodulated are selected to display  
25 an appropriate video channel on the television receiver 94 through the set top box 93.

[0006]

FIG. 3 shows the configuration of an FM batch conversion circuit using an optical-frequency modulation unit and an optical-frequency local oscillator unit that can be applied to this FM batch conversion method (for example, see Patent document 1, Non-patent document 2, and Non-patent document 3). The FM batch conversion circuit 81 shown in FIG. 3 comprises an optical-frequency modulation unit 101, an optical multiplexer unit 102, a photodiode 103 as an optical detection unit, and an optical-frequency local oscillator unit 104.

[0007]

Consider the optical-frequency modulation unit 101 frequency-modulating a carrier light source of optical frequency  $f_0$  at a frequency  $f_s$  in the FM batch conversion circuit 81. Representing a frequency shift by  $\delta f$ , an optical frequency of the optical signal  $F_{fml d}$  at an output of the optical-frequency modulation unit 101 is given by

$$F_{fml d} = f_0 + \delta f \cdot \sin(2\pi \cdot f_s \cdot t). \quad (1)$$

As the carrier light source of the optical-frequency modulation unit 101, a DFB-LD (Distributed Feed-Back Laser Diode, distributed feedback semiconductor laser) is used.

[0008]

The optical-frequency local oscillator unit 104 makes the oscillation light source oscillate a light of optical

frequency  $f_1$ , which is multiplexed with an optical signal from the optical-frequency modulation unit 101 in the optical multiplexer unit 102. A DFB-LD is used as the oscillation light source of the optical-frequency local oscillator unit 104. Two optical signals multiplexed in the optical multiplexer unit 102 are detected in an optical detection unit 103. The opto-heterodyne is applied as a detection method and a photodiode is used as the detection element. The frequency  $f$  of the detected electrical signal is given by

$$f = f_0 - f_1 + \delta f \cdot \sin(2\pi \cdot f_s \cdot t). \quad (2)$$

Here, if the optical frequency of the carrier light source of the optical-frequency modulation unit 101 and that of the oscillation light source of the optical-frequency local oscillator unit 104 are brought close to each other, an electrical signal whose intermediate frequency  $f_i = f_0 - f_1$  is a few GHz and that is frequency-modulated with a frequency shift  $\delta f$ , as shown in FIG. 2B, can be obtained.

[0009]

Since generally, when the DFB-LD is modulated by an injected current, its optical frequency varies with the injection current in a width of a few GHz, a value of a few GHz can be obtained as the frequency shift  $\delta f$ . For example, multichannel AM picture signals or QAM picture signals that have been frequency-division-multiplexed in

a frequency span ranging from about 90 MHz to about 750 MHz can be converted into a frequency-modulated signal in a band of about 6 GHz whose intermediate frequency  $f_i = f_o - f_l$  is about 3 GHz, as shown in FIG. 2A, using the  
5 FM batch conversion circuit.

[0010]

FIG. 4 shows an example of another FM batch conversion circuit that is applied to this FM batch conversion method and that uses two optical-frequency modulation units in  
10 a push-pull configuration. The FM batch conversion circuit 81 shown in FIG. 4 comprises a differential distributor 105, an optical-frequency modulation unit 106, an optical-frequency modulation unit 107, an optical multiplexer unit 102, and a photodiode as the optical  
15 detection unit 103.

[0011]

In the FM batch conversion circuit 81, the picture signals that have been frequency-division-multiplexed as shown in FIG. 2A are distributed to two electrical signals  
20 whose phases are inverted to each other in the differential distribution unit 105. When frequency modulation is performed on an optical signal using one electrical signal out of the two electrical signals from the differential distribution unit 105 as the modulation input and also  
25 using the carrier light source of optical frequency  $f_{ol}$  in the optical-frequency modulation unit 106, the optical frequency  $F_{fml1}$  of the optical signal at an output of



the optical-frequency modulation unit 106 is given by the following formula in the case of a frequency shift  $\delta f/2$ ,

$$F_{fml d1} = f_{o1} + (\delta f/2) \cdot \sin(2\pi \cdot f_s \cdot t). \quad (3)$$

5

Here, in Formula (3), the modulation signal is assumed to be a signal of frequency  $f_s$ . When frequency modulation is performed using the other electrical signal out of the two electrical signals from the differential distribution unit 105 as the modulation input and also using the carrier light source of optical frequency  $f_{o2}$  in the optical-frequency modulation unit 107, the optical frequency  $F_{fml d2}$  of the optical signal at the output of the optical-frequency modulation unit 106 is given by the following formula in the case of a frequency shift  $\delta f/2$ ,

15

$$F_{fml d2} = f_{o2} - (\delta f/2) \cdot \sin(2\pi \cdot f_s \cdot t) \quad (4)$$

In-Formula (4), the modulation signal is assumed to be a signal of frequency  $f_s$ . As carrier light sources of the optical-frequency modulation units 106 and 107, DFB-LDs (Distributed Feed-Back Laser Diodes, distributed feedback semiconductor lasers) can be used.

20

[0012]

25

The outputs from the optical-frequency modulation units 106 and 107 are multiplexed in the optical multiplexer unit 102, and two optical signals multiplexed

in the optical multiplexer unit 102 are heterodyne-detected in the optical detection unit 103. As the optical detection unit, photodiodes functioning as heterodyne detection elements can be used. The  
5 electrical signal that was heterodyne-detected in the optical detection unit 103 is an electrical signal whose frequency  $f$  equals a difference between values expressed by Formula (3) described above and by Formula (4) described above. That is, the frequency is given by

10  
$$f = f_{o1} - f_{o2} + \delta f \cdot \sin(2\pi \cdot f_s \cdot t). \quad (5)$$

However, the modulation signal is assumed to be a signal of frequency  $f_s$  in Formula (5). Here, if the optical  
15 frequency of the carrier light source of the optical-frequency modulation unit 106 and that of the oscillation light source of the optical-frequency local oscillator unit 107 are brought close to each other, an electrical signal whose intermediate frequency  $f_i = f_o$   
20 -  $f_l$  is a few GHz and that is frequency-modulated with a frequency shift  $\delta f$ , as shown in FIG. 2B, can be obtained.

[0013]

Generally, when the DFB-LD is modulated by an injected current, the optical frequency thereof is varied in a width  
25 of a few GHz in accordance with the injected current; therefore, a frequency shift  $\delta f$  of a few GHz can be obtained. For example, multichannel AM picture signals or QAM picture

signals that have been frequency-division-multiplexed in a frequency span ranging from about 90 MHz to about 750 MHz can be converted into a frequency-modulated signal in a band of about 6 GHz whose intermediate frequency  $f_i$  =  $f_o - f_l$  is set to about 3 GHz, as shown in FIG. 2B, by the FM batch conversion circuit.

[0014]

FIG. 5 shows another FM batch conversion circuit that is applied to this FM batch conversion method and that uses a voltage controlled oscillation element. The FM batch conversion circuit 81 shown in FIG. 5 is equipped with a voltage controlled oscillation unit 111 using a voltage controlled oscillation element.

[0015]

In the FM batch conversion circuit 81, when the picture signals that have been frequency-division-multiplexed as shown in FIG. 2A are frequency-modulated using a frequency  $f_o$  as a center frequency in the voltage controlled oscillation unit 111, the frequency  $f_v$  of an output electrical signal is given by the following formula in the case of a frequency shift  $\delta f$ .

$$f_v = f_o + \delta f \cdot \sin(2\pi \cdot f_s \cdot t) \quad (6)$$

Thus, the frequency-modulated signal with an intermediate frequency  $f_i = f_o$  and a frequency shift  $\delta f$  can be obtained. Note that the modulation signal is assumed to be a signal

of frequency  $f_s$  in Formula (6).

[0016]

For example, multichannel AM picture signals or QAM picture signals that have been  
5 frequency-division-multiplexed in a frequency span ranging from about 90 MHz to about 750 MHz can be converted into a frequency-modulated signal in a band of about 6 GHz, as shown in FIG. 2B, by the FM batch conversion circuit 81 with an intermediate frequency  $f_i = f_o$  being set to  
10 about 3 GHz.

[0017]

FIG. 6 shows an example of another FM batch conversion circuit that is applied to this FM batch conversion method and that uses two voltage controlled oscillation elements  
15 in a push-pull configuration. The FM batch conversion circuit 81 shown in FIG. 6 comprises the differential distribution unit 105, a voltage controlled oscillation unit 112, a voltage controlled oscillation unit 114, a  
20 mixer 115, and a low-pass filter 117.

[0018]

In the FM batch conversion circuit 81, the picture signals that have been frequency-division-multiplexed as shown in FIG. 2A are distributed to two electrical signals whose phases are inverted to each other in the differential  
25 distribution unit 105. When, using one electrical signal out of the two electrical signals from the differential distribution unit 105 as a modulation input, frequency

modulation that uses a frequency  $f_0$  as the center frequency is performed in the voltage controlled oscillation unit 112, the frequency  $f_{v1}$  of the output electrical signal is given by the following formula in the case of a frequency shift  $\delta f/2$ ,

$$f_{v1} = f_{o1} + (\delta f/2) \cdot \sin(2\pi \cdot f_s \cdot t). \quad (7)$$

That is, a frequency-modulated signal with an intermediate frequency  $f_i = f_{o1}$  and a frequency shift  $\delta f/2$  is obtained. In Formula (7), the modulation signal is assumed to be a signal of frequency  $f_s$ . When, using the electrical signal out of the two electrical signals from the differential distribution unit 105 as a modulation input, frequency modulation that uses a frequency  $f_{o1}$  as the center frequency in the voltage controlled oscillation unit 114 is performed, the frequency  $f_{v2}$  of the output electrical signal is given by the following formula in the case of a frequency shift  $\delta f/2$ ,

$$f_{v2} = f_{o2} - (\delta f/2) \cdot \sin(2\pi \cdot f_s \cdot t) \quad (8)$$

A frequency-modulated signal with an intermediate frequency  $f_i = f_{o2}$  and a frequency shift  $\delta f/2$  is obtained. In Formula (8), the modulation signal is assumed to be a signal of frequency  $f_s$ .

[0019]

The outputs from the voltage controlled oscillation units 112 and 114 are mixed by the mixer 115, and a signal into which the two electrical signals were mixed by the mixer 115 is smoothed by the low pass filter 117. The electrical signal smoothed by the low pass filter 117 that passes an electrical signal of a frequency equal to a difference between the intermediate frequency  $f_{o1}$  and the intermediate frequency  $f_{o2}$  becomes an electrical signal whose frequency equals a difference between values expressed by Formula (7) described above and by Formula (8) described above. That is, the frequency is given by

$$f = f_{o1} - f_{o2} + \delta f \cdot \sin(2\pi \cdot f_s \cdot t). (9)$$

15

In Formula (9), the modulation signal is assumed to be a signal of frequency  $f_s$ . Here, an electrical signal whose intermediate frequency  $f_i = f_{o1} - f_{o2}$  is a few GHz and that is frequency-modulated with a frequency shift  $\delta f$ , as shown in FIG. 2B, can be obtained.

20

[0020]

For example, multichannel AM picture signals or QAM picture signals that have been frequency-division-multiplexed in a frequency span ranging from about 90 MHz to about 750 MHz can be converted into a frequency-modulated signal in a band of about 6 GHz, as shown in FIG. 2B, with an intermediate frequency

25

$f_i = f_{o1} - f_{o2}$  being set to about 3 GHz by the FM batch conversion circuit.

[0021]

Heretofore, as a technique aiming at reduction of distortion, a pre-distortion circuit is known (for example, see Patent document 2). FIG. 7 shows the configuration of an optical signal transmission system using the conventional FM batch conversion method in which a predistortion circuit is applied to distortion compensation of the FM batch conversion circuit. The optical signal transmission system shown in FIG. 7 comprises: the optical signal transmitter 80 having a predistortion circuit 86, the FM batch conversion circuit 81, the light source 82 as a transmitter circuit, and the optical amplifier circuit 83; the optical transmission path 85; the optical signal receiver 90 having the photoelectric conversion circuit 91 and the FM demodulator circuit 92; the set top box 93; and the television receiver 94. Signal spectra A, B, and C in FIG. 7 become frequency spectra shown in FIG. 2A, FIG. 2B, and FIG. 2C, respectively.

[0022]

When multichannel AM picture signals or QAM picture signals are inputted into the predistortion circuit 86, the predistortion circuit 86 adds beforehand a distortion inverse to a distortion that the FM batch conversion circuit 81 etc. will generate, and thereby compensates

the distortion generated by the subsequent FM batch conversion circuit 81 etc. An output of the predistortion circuit 86 is frequency-modulated by the FM batch conversion circuit 81, converted from the electrical  
5 signal to an optical signal by the light source 82, optically amplified by the optical amplifier circuit 83, and subsequently transmitted in the optical transmission path 85. The transmitted optical signal passes through the optical transmission path 85, is converted to an  
10 electrical signal by the photoelectric conversion circuit 91 of the optical signal receiver 90, and frequency-demodulated to yield the original AM picture signals or QAM picture signals by the FM demodulator circuit 95.

15 [0023]

FIG. 8 shows an example of the configuration of the predistortion circuit. The predistortion circuit 86 shown in FIG. 8 comprises an inphase distribution unit 121, a delay line 122, a distortion generator circuit 123,  
20 an amplitude adjusting unit 124, a delay adjusting unit 125, and a differential combining unit 126. The multichannel AM picture signals or QAM picture signals inputted into the inphase distribution unit 121 are split into two sets of signals. One set of split signals is  
25 added with a distortion that will generate in the FM batch conversion circuit etc. by the distortion generation circuit 123, and their amplitudes and delays are adjusted



by the amplitude adjusting unit 124 and the delay adjusting unit 125, respectively. The other set of split signals is delayed by the delay line 122. The signals outputted from the delay adjusting unit 125 and those outputted from the delay line 122 are combined in the differential combining unit 126. As a result, the signal outputted from the differential combining unit 126 becomes a signal to which a distortion inverse to a distortion that the FM batch conversion circuit etc. will generate is added beforehand.

[0024]

On the other hand, as a frequency demodulator circuit method, there is a delay line detection method. FIG. 9 shows the configuration of the FM demodulator circuit based on delay line detection that is applicable to the optical signal receiver 90. The FM demodulator circuit 92 shown in FIG. 9 comprises a limiting amplifying unit 131, a delay line 132, an AND gate 133, and a low pass filter 134.

[0025]

In the FM demodulator circuit 92, the inputted frequency-modulated optical signal is shaped into a rectangular wave by the limiting amplifying unit 131. An output of the limiting amplifying unit 131 is split into two outputs; one output is inputted into an input terminal of the AND gate 133, and the other output is inputted into an input terminal of the AND gate 133 after being inverted in polarity and delayed by a time  $\tau$  by the delay line 132.

When this output of the AND gate 133 is smoothed by the low pass filter 134, the output will become a frequency-demodulated output (for example, see Non-patent document 2). It is known that an OR gate is also applicable instead of an AND gate (for example, see Patent document 3).

[0026]

Such transmission of multichannel picture signals requires low distortion. In Non-patent document 2, CNR (Carrier-to-Noise Ratio) is set to 42 dB or more, and CSO (Composite Second-Order Distortion) and CTB (Composite Triple Beat) are set to -54 dB or less in an optical signal transmitter and an optical signal transmission system that use the FM batch conversion method.

[0027]

However, in the conventional FM demodulator circuit, the delay line 132 has a characteristic that the delay line 132 has different delay times at low frequencies and at high frequencies due to impedance mismatching at both ends of the delay line 132 used for the delay line detection, or other reasons. That is, phase distortion developed between low frequencies and high frequencies. As a result, CSO and CTB will deteriorate by the phase distortion between low frequencies and high frequencies.

[0028]

In the optical signal receiver using the conventional FM batch conversion method, CSO and CTB have reached to

saturated values slightly exceeding -54 dB. If the FM demodulator circuit of the optical signal receiver can be configured with lower distortion, improvement in the transmission characteristic can be expected.

5

Patent document 1: Japanese Patent No. 2700622

Patent document 2: Japanese Patent No. 3371355

Patent document 3: Japanese Patent Application  
Laid-open No. 2002-141750

10

Non-patent document 1: ITU-T Standard J-185

"Transmission Equipment for transferring multi-channel television signals over optical access networks by FM conversion," ITU-T

Non-patent document 2: N. Shibata et al. "Optical video  
15 distribution system using FM batch conversion method,"  
The IEICE Transaction B (Japanese Edition), Vol. J83-B,  
No. 7, pp. 948-959, July 2000

Non-patent document 3: Suzuki et al. "Pulsed FM batch  
conversion modulation analog optical CATV distribution  
20 system," IEICE Autumn Society Conference, Technical  
Digest, B-603, 1991

#### DISCLOSURE OF THE INVENTION

[0029]

25

It was difficult to improve high-frequency phase distortion of the delay line used in the conventional FM demodulator circuit, and so it was difficult to realize

a low distortion characteristic. In accordance with the above, it is the object of this invention to realize an optical signal receiver using a low-distortion FM demodulator circuit, optical signal receiving equipment,  
5 and an optical signal transmission system using either the optical signal receiver or the optical signal receiving equipment.

[0030]

To achieve this object, this invention is an optical  
10 signal receiver that receives and frequency-demodulates an optical signal, comprising: an optical branch circuit for splitting an input optical signal into two signals; an optical delay line for delaying one of the two branched optical signals; a first photoelectric conversion circuit  
15 for converting the optical signal from the optical delay line into a first electrical signal; a second photoelectric conversion circuit for converting the other optical signal from the optical delay line into a second electrical  
--signal; --rectangular-wave-forming means that outputs a  
20 single rectangular-wave signal using the first electrical signal from the first photoelectric conversion circuit and the second electrical signal from the second photoelectric conversion circuit as inputs; and a  
smoothing circuit for smoothing the rectangular-wave  
25 signal from the rectangular-wave forming means.

[0031]

The other aspect of this invention is optical signal

receiving equipment that receives and frequency-demodulates an optical signal, comprising: (1) an optical branch device for splitting an input optical signal into N signals (N is an integer of 2 or more); (2) 5 N optical signal receivers each of which has: an optical branch circuit for splitting the optical signal from the optical branch circuit into two signals; an optical delay line for delaying one of the two branched optical signals; a first photoelectric conversion circuit for converting 10 the optical signal from the optical delay line into a first electrical signal; a second photoelectric conversion circuit for converting the other optical signal from the optical delay line into a second electrical signal; rectangular-wave forming means that outputs a single 15 rectangular-wave signal using the first electrical signal from the first photoelectric conversion circuit and the second electrical signal from the second photoelectric conversion circuit as inputs; and a smoothing circuit for ~~smoothing the rectangular-wave signal from the~~ 20 rectangular-wave forming means; and (3) an inphase combiner that combines the N smoothed rectangular-wave signals outputted from the N optical signal receivers, respectively, being in phase with one another.

[0032]

25 The further other aspect of this invention is an optical signal transmission system that uses the FM batch conversion method, comprising: (1) an optical signal

transmitter equipped with an FM batch conversion circuit;  
and (2) an optical signal receiver having: an optical  
branch circuit that is connected to the optical signal  
transmitter through an optical transmission path and  
5 splits an optical signal from the optical signal  
transmitter into two signals; an optical delay line for  
delaying one of the two branched optical signals; a first  
photoelectric conversion circuit for converting the  
optical signal from the optical delay line into a first  
10 electrical signal; a second photoelectric conversion  
circuit for converting the other optical signal out of  
the two branched optical signals into a second electrical  
signal; rectangular-wave forming means for outputting a  
single rectangular-wave signal using the first electrical  
15 signal from the first photoelectric conversion circuit  
and the second electrical signal from the second  
photoelectric conversion circuit as inputs; and a  
smoothing circuit for smoothing the rectangular-wave  
signal from the rectangular-wave forming means.

20 [0033]

The optical signal receiver, the optical signal  
receiving equipment, and the optical signal transmission  
system of this invention can achieve excellent  
transmission characteristics, since the high-frequency  
25 phase distortion of the delay line is improved by using  
the optical delay line, such as optical fibers and  
planer-type optical waveguides, for a delay line.

[0034]

Further, when the low distortion characteristic can be achieved, it will become possible to improve the receiving quality of a picture signal.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0035]

[FIG. 1]

FIG. 1 is a diagram explaining the configuration of the conventional optical signal receiver and the optical signal transmission system that use the FM batch conversion method.

[FIG. 2A]

FIG. 2A is a diagram explaining the signal spectra in the optical signal receiver and the optical signal transmission system.

[FIG. 2B]

~~FIG. 2B is a diagram explaining the signal spectrum~~  
in the optical signal receiver and the optical signal transmission system.

[FIG. 2C]

FIG. 2C is a diagram explaining the signal spectra in the optical signal receiver and the optical signal transmission system.

[FIG. 3]

FIG. 3 is a block diagram of the FM batch conversion

circuit that uses the optical-frequency modulation unit and the optical-frequency local oscillator unit.

[FIG. 4]

FIG. 4 is a block diagram of the FM batch conversion  
5 circuit that uses the two optical-frequency modulation units in a push-pull configuration.

[FIG. 5]

FIG. 5 is a block diagram of the FM batch conversion  
circuit that uses a voltage controlled oscillation  
10 element.

[FIG. 6]

FIG. 6 is a block diagram of the FM batch conversion  
circuit that uses two voltage controlled oscillation  
elements in a push-pull configuration.

15 [FIG. 7]

FIG. 7 is a block diagram of an optical signal  
transmission system using the conventional FM batch  
conversion method in which a predistortion circuit is  
applied to distortion compensation of the FM batch  
20 conversion circuit.

[FIG. 8]

FIG. 8 is an illustrative block diagram of the  
predistortion circuit.

[FIG. 9]

25 FIG. 9 is a block diagram of an FM demodulator circuit  
applicable to the optical signal receiver.



[FIG. 10]

FIG. 10 is a block diagram of an optical signal receiver of Embodiment 1.

[FIG. 11]

5        FIG. 11 is a diagram explaining signal waveforms in several points of the optical signal receiver of Embodiment 1.

[FIG. 12]

10       FIG. 12 is a diagram explaining a frequency demodulation characteristic of the optical signal receiver of Embodiment 1.

[FIG. 13]

FIG. 13 is a block diagram of an optical signal receiver of Embodiment 2.

15       [FIG. 14]

FIG. 14 is a diagram explaining signal waveforms in several points of the optical signal receiver of Embodiment 2.

[FIG. 15]

20       FIG. 15 is a diagram explaining a frequency demodulation characteristic of the optical signal receiver of Embodiment 2.

[FIG. 16]

25       FIG. 16 is a block diagram of an optical signal receiver of Embodiment 3.

[FIG. 17]

FIG. 17 is a diagram explaining signal waveforms in

several points of the optical signal receiver of Embodiment 3.

[FIG. 18]

FIG. 18 is a block diagram of an optical signal receiver of Embodiment 4.

[FIG. 19]

FIG. 19 is a diagram explaining signal waveforms in several points of the optical signal receiver of Embodiment 4.

[FIG. 20]

FIG. 20 is a block diagram of optical signal receiving equipment of Embodiment 5.

[FIG. 21]

FIG. 21 is a block diagram of an optical transmitter that performs intensity modulation after converting optical signals into pulses in an optical signal transmission system of Embodiment 6.

[FIG. 22]

~~FIG. 22 is a diagram explaining signal waveforms in~~  
several points of the optical transmitter that performs intensity modulation after converting optical signals into pulses in the optical signal transmission system of Embodiment 6.

BEST MODE FOR CARRYING OUT THE INVENTION

[0036]

Hereafter, embodiments of this invention will be

described referring to the drawings.

[0037]

#### Embodiment 1

5        This embodiment is an optical signal receiver for performing delay detection using an optical delay line. FIG. 10 shows the configuration of the optical signal receiver according to this embodiment. An optical signal receiver 10 shown in FIG. 10 comprises an optical amplifier  
10    circuit 11, an optical branch circuit 13, an optical delay line 15, a first photoelectric conversion circuit 17, a first discrimination circuit 21, a second photoelectric conversion circuit 19, a second discrimination circuit 23, an AND circuit 25, and a smoothing circuit 12.

15        [0038]

Referring to FIG. 10, the configuration of the optical signal receiver of this embodiment will be described. The optical signal receiver 10 shown in FIG. 10 has a function of receiving and frequency-demodulating an optical signal  
20    that is frequency-modulated. Circuits and their operations of the optical signal receiver will be explained. The optical amplifier circuit 11 optically amplifies an optical signal inputted thereinto. As an optical amplifier circuit, semiconductor optical amplifier  
25    circuits or optical-fiber-type amplifier circuits can be used. When the optical power of the optical signal inputted into the first photoelectric conversion circuit

17 or the second photoelectric conversion circuit 19 to be described later is sufficient, the optical signal may be directly inputted into the optical branch circuit 13 omitting the optical amplifier circuit 11.

5        [0039]

The optical signal amplified in the optical amplifier circuit 11 is split into two signals in the optical branch circuit 13. As the optical branch circuit 13, optical-fiber-coupling-type optical branch circuits or  
10 planer-type optical branch circuits can be used. It is preferable that the branching ratio is adjusted so that the optical power of the optical signal inputted into the first photoelectric conversion circuit 17 to be described later becomes equal to the optical power of the optical  
15 signal inputted into the second photoelectric conversion circuit 19 to be described later.

[0040]

One of the two branched optical signals is delayed by the optical delay line 15 and subsequently inputted  
20 into the first photoelectric conversion circuit 17. The other of the two branched optical signals is inputted into the second photoelectric conversion circuit 19. As the optical delay line 15, optical fibers or planer-type optical waveguides can be used. Moreover, the optical  
25 delay line 15 and the optical branch circuit 13 can be constructed in one piece. Each of the first photoelectric conversion circuit 17 and the second photoelectric

conversion circuit 19 converts an optical signal into an electrical signal, amplifies the electrical signal if needed, and outputs it to either the first discrimination circuit 21 or the second discrimination circuit 23. As  
5 the first photoelectric conversion circuit 17 and the second photoelectric conversion circuit 19, for example, photoelectric transducers of photodiodes, avalanche photodiodes, phototransistors, etc. are applicable. Since the optical delay line of this embodiment does not  
10 have such phase distortion at high frequencies as does the delay line in electrical circuits, an excellent frequency demodulation characteristic at high frequencies can be obtained.

[0041]

15 Each of the first discrimination circuit 21 and the second discrimination circuit 23 discriminates an electrical signal that is frequency-modulated by comparing its magnitude with a threshold, and converts  
~~it to a binary signal of a rectangular wave.~~ If the input  
20 optical signal has a duty ratio of 50%, the first discrimination circuit 21 and the second discrimination circuit 23 may be limiter amplifier circuits, respectively.

[0042]

25 The electrical signals from the first discrimination circuit 21 and from the second discrimination circuit 23 are frequency-demodulated by being processed by an AND

operation in the AND circuit 25 and by being smoothed in the smoothing circuit 12, respectively.

[0043]

FIG. 11 shows signal waveforms in several points of (M), (N), (P), (Q), and (R) in FIG. 10. (M), (N), (P), (Q), and (R) in FIG. 11 are signal waveforms in the points of (M), (N), (P), (Q), and (R) in FIG. 10. Hereafter, a frequency demodulation operation will be explained representing the instantaneous frequency of the optical signal inputted into the optical amplifier circuit 11 by  $f = 1/T$  and representing the delay time of the optical delay line 15 by  $\tau$

[0044]

The optical signal inputted into the first photoelectric conversion circuit 17 (FIG. 11(M)) is delayed by the delay line 15 by a time  $\tau$  as compared with the optical signal inputted into the second photoelectric conversion circuit 19 (FIG. 11(N)). The alternate long and short dash lines in FIG. 11(M) and (N) correspond to thresholds when the optical signal is discriminated by the first discrimination circuit 21 and by the second discrimination circuit 23 after the optical signal was processed by photoelectric conversion, respectively. The electrical signals processed by photoelectric conversion are discriminated by the first discrimination circuit 21 and by the second discrimination circuit 23 in terms of level, respectively, and converted to

rectangular waves while maintaining a delay time  $\tau$  (FIG. 11(P), (Q)). The two electrical signals of rectangular waves are processed by an AND operation in the AND circuit 25 and the original electrical signal is thinned in pulse width by  $\tau$  (FIG. 11(R)). Here, the AND operation is performed by positive logic. This electrical signal processed by the AND operation is smoothed by the smoothing circuit 12.

[0045]

The output voltage  $V_{out}$  of the smoothing circuit 12 is expressed by the following formula.

$$V_{out} = V_{ox}(T/2 - \pi)/T = V_{ox}(1/2 - \tau/T) = V_{ox}(1/2 - \tau \cdot f) \quad (10)$$

From Formula (10), a frequency demodulation characteristic as shown in FIG. 12 can be achieved. In FIG. 12, the horizontal axis denotes frequency  $f$ , and the vertical axis denotes output voltage  $V_{out}$  of smoothing circuit. Thus, since the output voltage of the smoothing circuit attenuates linearly with the frequency of the input optical signal, this optical signal receiver can implement a frequency demodulation function. Incidentally, the larger the delay  $\tau$ , the higher the frequency sensitivity of the output voltage becomes. However,  $\tau$  cannot be made larger than  $1/(2f)$ .

[0046]

As described above, the optical signal receiver of this embodiment can optically receive the optical signal that is frequency-modulated and implement a frequency demodulation function. Moreover, since the optical delay line does not have phase distortion at high frequencies, it can implement an excellent frequency demodulation characteristic at high frequencies. Incidentally, although this embodiment was described using FIG. 10, when the optical signal receiver receives the optical signal with sufficient optical power, the optical amplifier circuit 11 in FIG. 10 can be omitted.

[0047]

#### Embodiment 2

This embodiment is an optical signal receiver for performing delay detection using an optical delay line. FIG. 13 shows the configuration of the optical signal receiver according to this embodiment. The optical signal receiver 10 shown in FIG. 13 comprises the optical amplifier circuit 11, the optical branch circuit 13, the optical delay line 15, the first photoelectric conversion circuit 17, the first discrimination circuit 21, the second photoelectric conversion circuit 19, the second discrimination circuit 23, an OR circuit 27, and the smoothing circuit 12.

[0048]

Referring to FIG. 13, the configuration of this



embodiment will be described. The optical signal receiver 10 shown in FIG. 13 has a function of receiving and frequency-demodulating an optical signal that is frequency-modulated. Circuits and their operations of the optical signal receiver will be explained. The optical amplifier circuit 11 optically amplifies an optical signal inputted thereinto. As the optical amplifier circuit, semiconductor optical amplifier circuits or optical-fiber-type amplifier circuits can be used. When the optical power of the optical signal inputted into the first photoelectric conversion circuit 17 to be described later or the second photoelectric conversion circuit 19 to be described later is sufficient, the optical signal may be directly inputted into the optical branch circuit 13 omitting the optical amplifier circuit 11.

[0049]

The optical signal amplified in the optical amplifier circuit 11 is split into two signals in the optical branch circuit 13. As the optical branch circuit 13, optical-fiber-coupling-type optical branch circuits or planer-type optical branch circuits can be used. It is preferable that a branching ratio is adjusted so that the optical power of the optical signal inputted into the first photoelectric conversion circuit 17 to be described later becomes equal to the optical power of the optical signal inputted into the second photoelectric conversion circuit

19 to be described later.

[0050]

One of the two branched optical signals is delayed by the optical delay line 15, and subsequently inputted into the first photoelectric conversion circuit 17. The other of the two branched optical signals is inputted into the second photoelectric conversion circuit 19. As the optical delay line 15, optical fibers or planer-type optical waveguides can be used. Moreover, the optical delay line 15 and the optical branch circuit 13 can be constructed in one piece. Each of the first photoelectric conversion circuit 17 and the second photoelectric conversion circuit 19 converts an optical signal into an electrical signal, amplifies the electrical signal if needed, and outputs it to the first discrimination circuit 21 or the second discrimination circuit 23. As the first photoelectric conversion circuit 17 and the second photoelectric conversion circuit 19, for example, ~~photoelectric transducers of photodiodes, avalanche~~ photodiodes, phototransistors, etc. are applicable. Since the optical delay line of this embodiment does not have such phase distortion at high frequencies as does the delay line in electrical circuits, an excellent frequency demodulation characteristic at high frequencies can be achieved.

[0051]

Each of the first discrimination circuit 21 and the

second discrimination circuit 23 discriminates the electrical signal that is frequency-modulated in the amplitude axis direction by comparing its magnitude with a threshold, respectively, and generates a binary signal  
5 of a rectangular wave. If the input optical signal has a duty ratio of 50%, the first discrimination circuit 21 and the second discrimination circuit 23 may be limiter amplifiers, respectively.

[0052]

10 The electrical signals from the first discrimination circuit 21 and from the second discrimination circuit 23 are processed by an OR operation in the OR circuit 27 and further smoothed by the smoothing circuit 12, and thereby frequency-demodulated.

15 [0053]

FIG. 14 shows signal waveforms in several points of (M), (N), (P), (Q), and (S) in FIG. 13. (M), (N), (P), (Q), and (S) in FIG. 14 are the signal waveforms in the  
~~points of (M), (N), (P), (Q), and (S) in FIG. 13.~~ Hereafter,  
20 the frequency demodulation operation will be explained representing the instantaneous frequency of the optical signal inputted into the optical amplifier circuit 11 by  $f = 1/T$  and representing the delay time of the optical delay line 15 by  $\tau$ .

25 [0054]

The optical signal inputted into the first photoelectric conversion circuit 17 (FIG. 14(M)) is

delayed by the optical delay line 15 by a time  $\tau$  as compared with the optical signal (FIG. 14(N)) inputted into the second photoelectric conversion circuit 19. The alternate long and short dash lines in FIG. 14(M) and (N) correspond to thresholds used when the electrical signal is discriminated by the first discrimination circuit 21 and by the second discrimination circuit 23, respectively, after being processed by photoelectric conversion. The electrical signals processed by the photoelectric conversion are discriminated in level by the first discrimination circuit 21 and by the second discrimination circuit 23, and converted to rectangular waves while maintaining the delay time  $\tau$  (FIG. 14(P), (Q)). The two electrical signals of rectangular waves are processed by an OR operation in the OR circuit 27 and an electrical signal whose pulse width is widened by  $\tau$  is generated (FIG. 14(S)). Here, the OR operation is performed by positive logic. This electrical signal processed by an OR operation is smoothed by the smoothing circuit 12.

[0055]

The output voltage  $V_{out}$  of the smoothing circuit 12 is expressed by the following formula.

$$V_{out} = V_{ox}(T/2 + \tau)/T = V_{ox}(1/2 + \tau/T) = V_{ox}(1/2 + \tau \cdot f)$$

(11)

From Formula (11), a frequency demodulation

characteristic as shown in FIG. 15 can be achieved. In FIG. 15, the horizontal axis denotes frequency  $f$  and the vertical axis denotes output voltage  $V_{out}$  of smoothing circuit. Thus, since the output voltage of the smoothing  
5 circuit increases linearly with the frequency of the input optical signal, this optical signal receiver can implement a frequency demodulation function.

[0056]

As described above, the optical signal receiver of  
10 this embodiment can optically receive the optical signal that is frequency-modulated and implement the frequency demodulation function. Moreover, since the optical delay line does not have phase distortion at high frequencies, the optical receiver can realize an excellent frequency  
15 demodulation characteristic at high frequencies.

Incidentally, although this embodiment was described using FIG. 13, when the optical signal receiver receives optical signals with sufficient optical power, the optical  
amplifier circuit 11 in FIG. 13 can be omitted.

20 [0057]

### Embodiment 3

This embodiment is an optical signal receiver for performing delay detection using an optical delay line. FIG. 16 shows the configuration of the optical receiver  
25 according to this embodiment. The optical signal receiver 10 shown in FIG. 16 comprises the optical amplifier circuit 11, the optical branch circuit 13, the

optical delay line 15, the first photoelectric conversion circuit 17, a first limiter amplifier circuit 41, the second photoelectric conversion circuit 19, a second limiter amplifier circuit 42, an adder circuit 43, a high-level discriminator 44, and the smoothing circuit 12.

[0058]

Referring to FIG. 16, the configuration of an optical signal receiver of this embodiment will be described. The optical signal receiver 10 shown in FIG. 16 has a function of receiving and frequency-demodulating an optical signal that is frequency-modulated. Circuits and their operations of the optical signal receiver will be explained. The optical amplifier circuit 11 optically amplifies the input optical signal. As the optical amplifier circuit, semiconductor optical amplifier circuits or optical-fiber-type amplifier circuits can be used. When the optical power of the optical signal inputted into the first photoelectric conversion circuit 17 to be described later or the second photoelectric conversion circuit 19 to be described later is sufficient, the optical signal may be directly inputted into the optical branch circuit 13 omitting the optical amplifier circuit 11.

[0059]

The optical signal amplified in the optical amplifier circuit 11 is split into two signals in the optical branch circuit 13. As the optical branch circuit 13,

optical-fiber-coupling-type optical branch circuits or planer-type optical branch circuits can be used. It is preferable that a branching ratio is adjusted so that the optical power of the optical signal inputted into the first photoelectric conversion circuit 17 to be described later becomes equal to the optical power of the optical signal inputted into the second photoelectric conversion circuit 19 to be described later.

[0060]

One of the two branched optical signals is delayed by the optical delay line 15, and subsequently inputted into the first photoelectric conversion circuit 17. The other of the two branched optical signals is inputted into the second photoelectric conversion circuit 19. As the optical delay line 15, optical fibers or planer-type optical waveguides can be used. Moreover, the optical delay line 15 and the optical branch circuit 13 can be constructed in one piece. Each of the first photoelectric conversion circuit 17 and the second photoelectric conversion circuit 19 converts an optical signal into an electrical signal, amplifies the electrical signal if needed, and outputs it to the first limiter amplifier circuit 41 or the second limiter amplifier circuit 42. As the first photoelectric conversion circuit 17 and the second photoelectric conversion circuit 19, for example, photoelectric transducers of photodiodes, avalanche photodiodes, phototransistors, etc. are applicable.

Since the optical delay line of this embodiment does not have such phase distortion at high frequencies as does the delay line in electrical circuits, an excellent frequency demodulation characteristic at high  
5 frequencies can be achieved.

[0061]

Each of the first limiter amplifier circuit 41 and the second limiter amplifier circuit 42 limits and amplifies an electrical signal that is  
10 frequency-modulated in the amplitude axis direction, and outputs a binary signal of a rectangular wave. Instead of the first limiter amplifier circuit 41 and the second limiter amplifier circuit 42, automatic-gain-control amplifier circuits that amplify the electrical signals  
15 to the predetermined amplitudes can be used, respectively.

[0062]

The electrical signals from the first limiter amplifier circuit 41 and the second limiter amplifier circuit 42 are added in the adder circuit 43 to yield a  
20 ternary signal. The electrical signal that has become a ternary signal is discriminated in the amplitude axis direction with a threshold existing between a level when the optical signal is inputted into both the first photoelectric conversion circuit 17 and the second  
25 photoelectric conversion circuit 19 and a level when the optical signal is inputted into either the first photoelectric conversion circuit 17 or the second



photoelectric conversion circuit 19 in the high-level discriminator 44. The electrical signal that was converted to a binary signal again by the high-level discriminator 44 is frequency-demodulated by being  
5 smoothed in the smoothing circuit 12.

[0063]

FIG. 17 shows the signal waveforms in several points of (M), (N), (P), (Q), (T), and (U) in FIG. 16. (M), (N), (P), (Q), (T), and (U) in FIG. 17 are signal waveforms  
10 in the points of (M), (N), (P), (Q), (T), and (U) in FIG. 16. Hereafter, the frequency demodulation operation will be explained representing the instantaneous frequency of the optical signal inputted into the optical amplifier circuit 11 by  $f = 1/T$  and representing the delay time of  
15 the optical delay line 15 by  $\tau$ .

[0064]

The optical signal inputted into the first photoelectric conversion circuit 17 (FIG. 17(M)) is delayed by the optical delay line 15 by a time  $\tau$  as compared  
20 with the optical signal inputted into the second photoelectric conversion circuit 19 (FIG. 17(N)). The alternate long and short dash lines in FIG. 17(M) and (N) correspond to thresholds when the electrical signals are limited and amplified by the first limiter amplifier  
25 circuit 41 and by the second limiter amplifier circuit 42, respectively, after being processed by the photoelectric conversion. The electrical signals

processed by the photoelectric conversion are limited and amplified by the first limiter amplifier circuit 41 and by the second limiter amplifier circuit 42, respectively, becoming rectangular waves while maintaining a delay time T (FIG. 17(P), (Q)). The two electrical signals of rectangular waves are added in the adder circuit 43 to yield a ternary signal (FIG. 17(T)). The ternary signal is discriminated in an amplitude axis direction by the high-level discrimination circuit comparing its magnitude with a threshold (FIG. 17(U)). The threshold used for discrimination exists between the level when the optical signal is inputted into both the first photoelectric conversion circuit 17 and the second photoelectric conversion circuit 19 and the level when the optical signal is inputted into either the first photoelectric conversion circuit 17 or the second photoelectric conversion circuit 19. The alternate long and short dash line in FIG. 17(T) indicates the threshold. The electrical signal (FIG. 17(U)) that becomes a binary signal by the high-level discrimination circuit is smoothed by the smoothing circuit 12.

[0065]

The output voltage  $V_{out}$  of the smoothing circuit 12 is expressed by the following formula.

$$V_{out} = V_{ox}(T/2 - \tau)/T = V_{ox}(1/2 - \tau/T) = V_{ox}(1/2 - \tau \cdot f) \quad (12)$$

From Formula (12), a frequency demodulation characteristic as shown in FIG. 12 can be achieved. Thus, since the output voltage of the smoothing circuit  
5 attenuates linearly with the frequency of the input optical signal, this optical signal receiver can implement a frequency demodulation function. Although the larger the delay  $\tau$ , the higher the frequency sensitivity of the output voltage becomes,  $\tau$  cannot be made larger than  $1/(2f)$  because  
10 of Formula (12).

[0066]

As described above, the optical signal receiver of this embodiment can optically receive the optical signal that is frequency-modulated and implement a frequency  
15 demodulation function. Moreover, since the optical delay line does not have phase distortion at high frequencies, the optical signal receiver can achieve an excellent frequency demodulation characteristic at high frequencies. Incidentally, although this embodiment was  
20 described using FIG. 16, when the optical signal receiver receives the optical signal with sufficient optical power, the optical amplifier circuit 11 in FIG. 16 can be omitted.

[0067]

#### Embodiment 4

25 This embodiment is an optical signal receiver for performing delay detection using an optical delay line. FIG. 18 shows the configuration of the optical signal

receiver according to this embodiment. The optical signal receiver 10 shown in FIG. 18 comprises the optical amplifier circuit 11, the optical branch circuit 13, the optical delay line 15, the first photoelectric conversion circuit 17, the first limiter amplifier circuit 41, the second photoelectric conversion circuit 19, the second limiter amplifier circuit 42, the adder circuit 43, a low-level discriminator 45, and the smoothing circuit 12. The difference from FIG. 16 explained in Embodiment 3 is a point that the high-level discriminator 44 in FIG. 16 is changed with the low-level discriminator 45.

[0068]

Since the structural difference from Embodiment 3 is a difference between the high-level discriminator 44 and the low-level discriminator 45, the difference will be referred to. The threshold of the high-level discriminator 44 exists between the level when the optical signal is inputted into both the first photoelectric conversion circuit 17 and the second photoelectric conversion circuit 19 and the level when the optical signal is inputted into either the first photoelectric conversion circuit 17 or the second photoelectric conversion circuit 19. On the other hand, the threshold of the low-level discriminator 45 exists between the level when the optical signal is inputted into either the first photoelectric conversion circuit 17 or the second photoelectric conversion circuit 19 and a level when the optical signal

is inputted into neither the first photoelectric conversion circuit 17 nor the second photoelectric conversion circuit 19.

[0069]

5        FIG. 19 shows signal waveforms in several points of (M), (N), (P), (Q), (T), and (U) in FIG. 18. (M), (N), (P), (Q), (T), and (U) of FIG. 19 are the signal waveforms in the points of (M), (N), (P), (Q), (T), and (U) in FIG. 18. Hereafter, the frequency demodulation operation will  
10 be explained representing the instantaneous frequency of the optical signal inputted into the optical amplifier circuit 11 by  $f = 1/T$  and representing the delay time of the optical delay line 15 by  $\tau$ .

[0070]

15        The difference from Embodiment 3 is a threshold used for discrimination. The alternate long and short dash line in FIG. 19 (T) indicates the threshold. This threshold exists between the level when the optical signal is inputted into either the first photoelectric conversion  
20 circuit 17 or the second photoelectric conversion circuit 19 and the level when the optical signal is inputted into neither the first photoelectric conversion circuit 17 nor the second photoelectric conversion circuit 19. As a result, the output voltage  $V_{out}$  smoothed by the smoothing  
25 circuit 12 is expressed by the following formula.

$$V_{out} = V_{ox}(T/2 + \tau)/T = V_{ox}(1/2 + \tau/T) = V_{ox}(1/2 + \tau \cdot f) \quad (13)$$

[0071]

5 From Formula (13), a frequency demodulation characteristic as shown in FIG. 15 can be achieved. Thus, since the output voltage of the smoothing circuit increases linearly with the frequency of the input optical signal, this optical signal receiver can implement a frequency  
10 demodulation function.

[0072]

As described above, the optical signal receiver of this embodiment can receive and frequency-demodulate an optical signal that is frequency-modulated. Moreover,  
15 since the optical delay line does not have phase distortion at high frequencies, the optical signal receiver can realize an excellent frequency demodulation characteristic at high frequencies. Although this  
~~embodiment was described using FIG. 18, when the optical~~  
20 signal receiver receives an optical signal with sufficient optical power, the optical amplifier circuit 11 in FIG. 18 can be omitted.

[0073]

Embodiment 5

25 This embodiment is optical signal receiving equipment that improves a noise characteristic using difference in additivity between signal and noise. FIG. 20 shows the

optical signal receiving equipment according to this embodiment. Optical signal receiving equipment 20 shown in FIG. 20 comprises an optical amplifier 61, an optical branch device 63, optical signal receivers 10-1, 10-2 and 10-3 that are any of the optical signal receivers according to Embodiments 1 through 4, and an inphase combiner 65.

[0074]

Referring to FIG. 20, the configuration of the optical signal receiving equipment of this embodiment will be described. The optical signal receiving equipment 20 shown in FIG. 20 has a function of receiving and frequency-demodulating an optical signal that is frequency-modulated. Circuits and their operations of the optical signal receiving equipment 20 will be explained. The optical amplifier 61 amplifies an optical signal inputted thereinto and outputs it. When the optical power of an optical signal inputted into the optical signal receiver to be described later is sufficient, the optical signal may be directly inputted into the optical branch device 63 omitting the optical amplifier 61.

[0075]

The optical branch device 63 splits an input optical signal into three signals. Although FIG. 20 shows an example of splitting into three, the input optical signal may be split into N signals (N is an integer of two or more). In this case, the N branched optical signals will be inputted into N optical signal receivers. The optical

signals inputted into the optical signal receivers 10-1, 10-2, and 10-3 are frequency-demodulated, respectively.

[0076]

5       The inphase combiner 65 combines electrical signals that are frequency-demodulated by the optical signal receivers 10-1, 10-2, and 10-3 being in phase with one another. If the electrical signals from the optical signal receivers 10-1, 10-2, and 10-3 are set to be in  
10   phase with one another, regarding the combined electrical signal by the inphase combiner 65, signal components are added in terms of voltage whereas noise components are added in terms of electric power.

[0077]

15       Representing the signal components of the electrical signals from three optical signal receivers by  $V_{s1}$ ,  $V_{s2}$ , and  $V_{s3}$ , respectively, and assuming that they are equal, i.e.,  $V_{s1} = V_{s2} = V_{s3} = V_s$ , the total sum voltage  $V_{st}$  of  
--- the signal components outputted by the inphase combiner  
20   65 is given by

$$V_{st} = V_{s1} + V_{s2} + V_{s3} = 3 \times V_s. \quad (14)$$

[0078]

25       Representing the output impedance of the inphase combiner 65 by  $R$ , when only one of the three optical signal receivers inputs a signal into the inphase combiner 65,



an electric power  $P_{s1}$  of the signal component of an electrical signal outputted by the inphase combiner 65 is given by

5  $P_{s1} = (V_s)^2/R. \quad (15)$

[0079]

When three optical signal receivers input optical signals into the inphase combiner 65, an electric power  
10  $P_{st}$  of the signal component of an electrical signal outputted by the inphase combiner 65 is given by

$$P_{st} = (V_{st})^2/R = (3 \times V_s)^2/R = 9 \times (V_s)^2/R. \quad (16)$$

15 [080]

On the other hand, representing the electric powers of noise components outputted from the three optical signal receivers by  $P_{n1}$ ,  $P_{n2}$ , and  $P_{n3}$ , respectively, when they  
~~are all equal, i.e.,  $P_{n1} = P_{n2} = P_{n3} = P_n$ , a total sum~~  
20  $P_{nt}$  of the noise components of the electrical signals outputted by the inphase combiner 65 is given by

$$P_{nt} = P_{n1} + P_{n2} + P_{n3} = 3 \times P_n. \quad (17)$$

25 [0081]

When only one of the three optical signal receivers inputs an optical signal into the inphase combiner 65,

the electric power of the noise component of the electrical signal outputted by the inphase combiner 65 is given by

$$P_{n1} = P_n. \quad (18)$$

5

[0082]

These formulas indicate that, when the electrical signals from three optical signal receivers are combined being in phase with one another, a power ratio of a signal component of  $20 \times \log(3)$  is obtained as compared with the electrical signal from a single optical signal receiver, but an electric power ratio of a noise component becomes  $10 \times \log(3)$  [dB] in the same comparison; therefore, the signal-to-noise ratio (electric power) at the output of the inphase combiner 65 is improved by  $10 \times \log(3)$  [dB].

15

[0083]

In this embodiment, the case of  $N = 3$  (i.e., the case of three electrical signals outputted by the three optical signal receivers) was explained. In the case where the number of electrical signals outputted from the optical signal receivers is  $N$  ( $N$  is an integer of two or more), the signal-to-noise ratio (electric power) can be improved by  $10 \times \log(N)$  [dB] as compared with the case of an electrical signal outputted from a single optical signal receiver.

20

[0084]

25

In addition, regarding the distortion, if the distortion characteristics of electrical signals

outputted from N optical signal receivers are inversely distorted, optical signals will cancel out one another in inphase combining, and consequently lower distortion can be achieved as compared with the case of a single optical signal receiver.

[0085]

#### Embodiment 6

This embodiment is an optical signal transmission system that uses any of the optical signal receivers and the optical signal receiving equipment according to claims 1 through 5. Referring to FIG. 1, the optical signal transmission system of this embodiment will be described. In this embodiment, the system comprises the optical signal transmitter 80 shown in FIG. 1 and either the optical signal receiver or the optical signal receiving equipment according to Embodiments 1 through 5 that is connected to the optical signal transmitter 80 through the optical fiber transmission path 85.

[0086]

Multichannel AM picture signals or QAM picture signals that have been frequency-division-multiplexed are inputted into an FM batch conversion circuit 81 of the optical signal transmitter 80 and frequency-modulated. The frequency-modulated electrical signals are allowed to intensity-modulate a light source 82 to effect conversion from the electrical signal to an optical signal. This optical signal is optically amplified in an optical

amplification 83 and outputted to the optical transmission path 85. The optical signal from the optical signal transmitter 80 is received and frequency-demodulated by any of the optical signal receiver and the optical signal receiving equipment according to Embodiments 1 through 5 by means of the optical transmission path 85.

[0087]

The light source 82 can directly intensity-modulate an output of the FM batch conversion circuit 81 or intensity-modulate the output of the FM batch conversion circuit 81 after it was converted into pulses. FIG. 21 shows the configuration of the optical signal transmitter in the case when the signal is intensity-modulated after being converted into pulses. The optical signal transmitter 80 shown in FIG. 21 comprises the FM batch conversion circuit 81, a limiter circuit 88, the light source 82, and the optical amplifier circuit 83, and outputs an optical signal to the optical transmission path 85.

[0088]

Multichannel AM picture signals or QAM picture signals that have been frequency-division-multiplexed are frequency-modulated by the FM batch conversion circuit 81 of the optical signal transmitter 80. The limiter circuit 88 discriminates whether the electrical signal obtained by frequency modulation is equal to or more than a threshold or less than the threshold and performs a

limiting operation, whereby it can convert the electrical signal into pulses by shaping the waveform into a rectangular wave. FIG. 22 shows the signal waveforms in several points of the optical signal transmitter shown in FIG. 21. FIG. 22(D) and (E) are the signal waveforms in points of (D) and (E) in FIG. 21. The alternate long and short dash line in FIG. 22(D) is a threshold of the limiter circuit. If the limiter circuit performs a limiting operation on the frequency-modulated electrical signal, shown in FIG. 22(D), using a threshold of the limiter circuit, the electrical signal is shaped into a rectangular wave. Even when the FM signal thus converted into pulses is allowed to intensity-modulate the light source 82, the signal can be frequency-demodulated in an optical signal receiver or optical signal receiving equipment.

[0089]

Moreover, if the optical signal transmitter 80 equipped with the predistortion circuit 86, as shown in FIG. 7, is used, distortion generated in the optical signal transmitter, the optical signal receiver, and the optical signal receiving equipment can be reduced. That is, when the optical signal transmitter 80 in FIG. 7 is connected with any of the optical signal receivers and the optical signal receiving equipment according to Embodiments 1 through 5 by means of an optical transmission path, it becomes possible to transmit picture signals with less

distortion.

#### INDUSTRIAL APPLICABILITY

[0090]

5       The optical signal receiver and the optical signal  
receiving equipment of this invention can be applied to  
an optical signal transmission system that performs  
frequency modulation on various signals as well as picture  
signals and transmits/receives these signals. This  
10   optical signal transmission system can be applied not only  
to the case where a network configuration of optical  
transmission paths is of an SS (Single Star) topology but  
also to the case where a network configuration of optical  
transmission paths is of a PDS (Passive Double Star)  
15   topology.